

University of Groningen

The Industry Sources of Productivity Growth and Convergence

Inklaar, Robert

Published in:
The Oxford Handbook of Productivity Analysis

DOI:
[10.1093/oxfordhb/9780190226718.013.22](https://doi.org/10.1093/oxfordhb/9780190226718.013.22)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2018

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Inklaar, R. (2018). The Industry Sources of Productivity Growth and Convergence. In E. Grifell-Tatjé, K. Lovell, & R. Sickles (Eds.), *The Oxford Handbook of Productivity Analysis* (pp. 725-752). Oxford University Press. <https://doi.org/10.1093/oxfordhb/9780190226718.013.22>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Oxford Handbooks Online

The Industry Sources of Productivity Growth and Convergence

Robert Inklaar

The Oxford Handbook of Productivity Analysis

Edited by Emili Grifell-Tatjé, C. A. Knox Lovell, and Robin C. Sickles

Print Publication Date: Sep 2018

Subject: Economics and Finance, Business Economics, Labor and Demographic Economics

Online Publication Date: Sep 2018 DOI: 10.1093/oxfordhb/9780190226718.013.22

Abstract and Keywords

Industry-level productivity analysis can be a useful diagnostic tool to better understand why some countries show faster overall productivity growth and to direct research attention to parts of the economy that warrant more detailed scrutiny. This chapter illustrates these strengths in three applications, namely the Europe-US productivity growth gap since the mid-1990s, the sectoral sources of rapid convergence of productivity levels between advanced and emerging economies, and an analysis of the determinants of productivity growth and convergence. One conclusion is that a better understanding of productivity growth (or lack thereof) in services industries should still be an important goal of researchers aiming to understand cross-country growth differences.

Keywords: industry, productivity, Europe, economy, productivity analysis

22.1. Introduction

THE analysis of productivity at the industry level stands at the midway point between economy-wide and firm-level analyses. On the firm-level end of the spectrum, the survey by Syverson (2011) on “what determines productivity” is devoted to studies of the role of, for instance, management practices, competition, trade, innovation, and resource allocation, which are addressed most convincingly at the firm level. On the economy-wide end of the spectrum, aggregate productivity can shed light on, for instance, the sources

The Industry Sources of Productivity Growth and Convergence

of growth (Fernald and Jones 2014) or cross-country income differences (Caselli 2005). So what role is there for an industry perspective?

I would argue that a particular advantage of the industry level over the firm level is that it can deliver a more comprehensive and an international comparative perspective. In other words, a main advantage of industry-level analysis over firm-level analysis is that data can be drawn from National Accounts—which are publicly available—and that the output of all industries together add up to gross domestic product (GDP). In contrast, in firm-level studies, the manufacturing sector is heavily overrepresented, which limits the extent to which outcomes can be generalized.¹ Similarly, high-quality firm-level data, which cover a comprehensive set of firms and can be used to trace entry and exit, are typically confidential and cannot be easily used in an international comparative perspective.² Another challenge at the firm level is that, for almost any analysis, important pieces of information are not available at that level of detail. For instance, an industrial survey may provide information on firm revenues, but not on the prices charged (Foster, Haltiwanger and Syverson 2008). Similarly, information about the skill level of employees is also typically collected through household, rather than enterprise (p. 726) surveys.³ Industry identifiers, though, are usually part of all such surveys, which means that industry-level analysis can typically draw on a greater variety of data items.

Economy-wide analysis likewise has important shortcomings, which are best illustrated with the debate about the acceleration of US productivity growth, starting in 1995 and the comparison with Europe.⁴ In the United States, the debate was between Jorgenson and Stiroh (2000) and Oliner and Sichel (2000), who argued that there had been a substantial change in the US productivity growth pattern, while Gordon (2000) argued that the increase in productivity growth was highly localized in information technology (IT) production. This was not resolved until the more detailed work of Jorgenson, Ho, and Stiroh (2005) showed that increases in productivity growth were also apparent in many industries that used information and communications technology (ICT) intensively.⁵ Similarly, when comparing Europe and the United States, Timmer and van Ark (2005) showed that the EU-US growth gap could be explained by differences in the importance of the IT production sector, while van Ark, O'Mahony, and Timmer (2008) could later show that this aggregate picture concealed a large difference in productivity growth in the (ICT-intensive) market services.

This is not to say that industry-level analysis is without shortcomings. Just as economy-wide data can conceal important industry-level differences, so can industry data obscure differences in productivity across firms, as Chapter 18 of this *Handbook* illustrates. Another problem is measurement of industry output. One reason why many firm-level studies focus on manufacturing is that their production process is understood more clearly than that of many services, and we can more easily measure the price of their output. In services, more careful modeling and surveying are typically needed, and progress in this area is highly uneven across countries and industries.⁶ Finally, in a globalizing world where different stages of production are fragmented across borders, the concept of a domestic industry becomes less relevant. As a result, the same industry

may engage in very different activities in different countries. For example, the electronics industry in the United States will include design of the iPhone, while the same industry in China focuses on assembly of the iPhone. A more in-depth discussion of this problem is beyond the scope of this chapter, but is taken up in Chapter 21 of this volume.

This discussion suggests that the analysis of productivity at the industry level should be done where its strengths are greatest or the weaknesses of the alternatives make it the best choice. In the remainder of this chapter, I will present three examples of such applications. First, I will analyze the industry sources of transatlantic productivity growth differences, to examine whether the findings of van Ark et al. (2008) still hold in the face of data revisions and the more turbulent macroeconomic backdrop of the financial crisis. Second, for a broader set of countries, I will trace the industry origins of changes in aggregate cross-country productivity dispersion. One important question is whether the manufacturing sector is somehow special as a source of convergence, as suggested by the work of Rodrik (2013). Third, I examine to what extent the varied patterns of industry productivity growth and convergence can be explained using (p. 727) factors that play a role in determining productivity. This extends the analysis of Inklaar, Timmer, and van Ark (2008) and McMorrow, Röger, and Turrini (2010) to a broader set of countries and a more recent period.⁷

22.2. The Transatlantic Productivity Growth Gap

The growth experience of Europe relative to the United States since World War II can be characterized in two phases, namely a rapid convergence in GDP per hour worked from 1950 until the mid-1990s, followed by a period of divergence. Figure 22.1 illustrates this by plotting GDP per hour worked for the EU-15 (i.e., the 15 member-states of the European Union until 2004), relative to the United States. Also shown in the chart is GDP per capita, which has been fairly stable in relative terms since the early 1970s. The difference between the evolution in GDP per hour and GDP per capita is due to differences in hours worked per capita, which in general will reflect differences in labor market outcomes and different preferences for leisure.



[Click to view larger](#)

Figure 22.1 GDP per hour worked and GDP per capita in the EU-15 relative to the United States, 1950–2013.

Notes: EU-15 refers to the 15 member countries of the European Union until 2004: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

Source: The Conference Board Total Economy Database™, January 2014, <http://www.tcb.org/data/economydatabase/>.

The relative decline in GDP per hour worked is substantial: after peaking at 87% in 1995, the level in 2013 stood at only 78%, a relative level comparable to the early 1980s. This relative decline has been fairly constant over this 18-year period, suggesting a [\(p. 728\)](#) persistent source of growth differences. Moreover, the relative decline has been widespread across the EU-15: 13 of the 15 countries had a lower level of GDP per hour worked relative to the United States in 2013 than in

1995 (the exceptions were Ireland and Sweden).

At this economy-wide level of analysis, we can go one step further and assess whether differences in growth of GDP per hour worked are due to differences in the growth contribution from other inputs. For this, we rely on the growth accounting decomposition provided in the Total Economy Database of The Conference Board:

$$\Delta \ln Y_{it} = \bar{\alpha}_{it} \Delta \ln L_{it} + (1 - \bar{\alpha}_{it}) \Delta \ln K_{it} + \Delta \ln A_{it},$$

(22.1)

where Y is GDP in country i at t , α is the share of labor income in GDP, the upper-bar denotes a two-period average, L is labor input, K is capital input, and A is total factor productivity (TFP). The labor input index is based on data on hours worked by workers with different levels of educational attainment, giving greater weight to workers that earn higher wages and thus (are assumed to) have a higher marginal product. Similarly, the index for capital input is based on data for different capital assets, notably ICT assets and non-ICT assets—buildings, transport equipment, and other machinery. Here, too, the assumption is made that assets with higher marginal costs—like ICT assets, which depreciate rapidly and show falling prices over time—have higher marginal products. As detailed in Jorgenson (2005) and Hulten (2010), equating marginal products to marginal costs means assuming that firms are cost-minimizing price-takers in factor markets. Furthermore, under the assumption of perfect competition in output markets, income shares equal output elasticities.⁸

The Industry Sources of Productivity Growth and Convergence

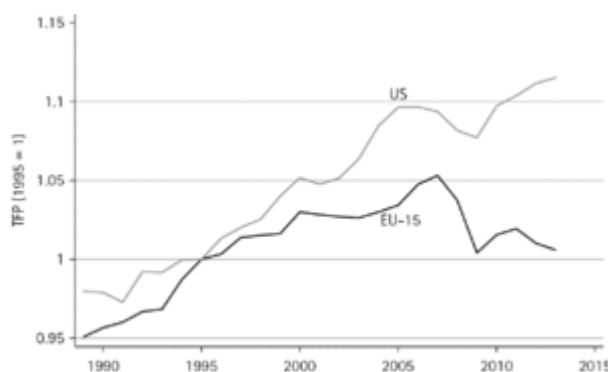
To relate the growth accounting decomposition to the pattern in Figure 22.1, equation (22.1) can be rewritten in terms of labor productivity:

$$\Delta \ln(Y_{it}/H_{it}) = \bar{\alpha}_{it} \Delta \ln(L_{it}/H_{it}) + (1 - \bar{\alpha}_{it}) \Delta \ln(K/H_{it}) + \Delta \ln A_{it}$$

(22.2)

where H is the total number of hours worked. From this equation, we can see that differences in labor productivity growth may be accounted for by differences in the pace of change in labor composition, $\Delta \ln(L_{it}/H_{it})$, differences in the rate of capital deepening, $\Delta \ln(K/H_{it})$, or differences in TFP growth, $\Delta \ln A_{it}$.

Figure 22.2 shows the development of TFP in the EU-15 and the United States since 1990, indexed to 1995 = 1. As the figure shows, TFP has grown by more than 10% in the United States over the period since 1995, while EU TFP was barely higher in 2013 than in 1995. In other words, the decline in Europe's relative labor productivity level from Figure 22.1 can be fully accounted for by lower TFP growth in Europe than in the United States. Indeed, the correlation between the relative changes in labor productivity and the relative changes in TFP is close to one. But what this actually says is that we do not really know what is behind the difference in labor productivity growth, since differences in the pace of change in labor composition or differences in capital deepening have no (overall) explanatory power. For individual countries within the EU-15, the TFP growth pattern is more mixed than the labor productivity growth pattern—with Austria, Finland, and Germany showing similar TFP growth as the United States, and Ireland and Sweden showing somewhat faster growth—but the United States has a clear growth advantage over the other 10 EU countries.



[Click to view larger](#)

Figure 22.2 Total factor productivity in the EU-15 and United States, 1989–2013 (1995 = 1).

Notes: EU-15 refers to the 15 member countries of the European Union until 2004: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

Source: The Conference Board Total Economy Database™, January 2014, <http://www.tcb.org/data/economydatabase/>.

To advance our understanding of these growth differences, we turn to an industry-level breakdown of total economy TFP growth. Note that this should be seen more as a diagnostic than an explanatory device: merely comparing growth in specific industries or groups of industries will not reveal *why* growth is faster. However, it can be helpful in suggesting where to look. For instance, if the United States has a TFP growth advantage in

industries that use ICT intensively, then the more specific question becomes why US firms are able to better use this technology to increase their productivity, for instance through better “people management” practices (Bloom, Sadun, and van Reenen 2012).

It is not straightforward, though, to gain a detailed industry perspective, as it requires not only the type of information that is regularly found in country National Accounts, on the value added, investments, and total employment of industries, but also data on the skill composition of the workforce and the asset composition of investment. Though collecting such data is feasible for numerous countries,⁹ it is much harder to achieve comprehensive and up-to-date country coverage. For the analysis here, I use the 2012 version of the EU KLEMS database,¹⁰ which includes data for the United States and for 10 of the EU-15 countries (representing 93% of EU-15 GDP), and covers the period through 2009 for all countries. Industry TFP growth is computed using an analogous growth accounting approach, as in equation (22.1), so industry TFP growth is equal to growth in industry value added minus cost-share-weighted growth of industry labor (p. 730) input and capital input. A helpful consequence of this is that we can decompose overall TFP growth into contributions by industries or groups of industries with comparable features. Specifically, aggregate TFP growth can be written as

$$\Delta \ln A_{it} = \sum_j \bar{v}_{ijt} \Delta \ln A_{ijt}$$

(22.3)

where $\Delta \ln A_{ijt}$ is the growth of TFP in industry j (in country i at time t) and v is the value-added share of industry j , $v_{ijt} = V_{ijt} / \sum_j V_{ijt}$ with V denoting value added at current prices and the upper bar indicating a two-period average. The same equation can be used to compute TFP growth for groups of industries.

Table 22.1 compares the TFP growth experience of the EU-10 and the United States between 1995 and 2009 for major industry groups. Note that, as Figure 22.2 shows, using 2009 as the final year of the comparison (a necessity given the coverage of EU KLEMS) is relatively flattering, as a larger growth gap has opened up in more recent years. In addition to average growth, the table shows the average value-added share of each group and the contribution to market economy TFP growth.

The Industry Sources of Productivity Growth and Convergence

Table 22.1 The Industry Composition of TFP Growth in the EU-10 and the United States, Average 1995–2009 (in %)

	TFP Growth		Share		Contribution	
	EU-10	US	EU-10	US	EU-10	US
Total economy	0.0	0.3	100	100		
Market economy	0.3	0.6	59	67	0.3	0.6
ICT production	2.8	5.9	7	7	0.3	0.6
Goods-producing industries	0.2	-0.4	21	20	0.1	-0.1
Market services	-0.3	0.2	31	40	-0.1	0.1
Distribution and trade	0.3	1.2	15	16	0.1	0.3
Finance and business services	-0.8	-0.5	12	18	-0.2	-0.1

The Industry Sources of Productivity Growth and Convergence

Personal services	-0.7	-0.9	4	6	-0.1	-0.1
-------------------	------	------	---	---	------	------

Notes: EU-10 includes Austria, Belgium, Finland, France, Germany, Italy, Netherlands, Spain, Sweden, and the United Kingdom. The share is the share in total economy value added. The growth contributions in the final columns are computed using equation (22.3). ICT production includes electronics manufacturing and information and communication services. Goods-producing industries include agriculture, mining, manufacturing (excluding electronics), utilities, and construction. The market economy includes all industries except government, health, education, for which output measurement is more challenging and likely more heterogeneous across countries, and real estate, for which output growth is equal to input growth for much of the industry.

Sources: Computations based on EU KLEMS database; see O'Mahony and Timmer (2009) and www.euklems.net.

(p. 731) Table 22.1 shows that the growth differential between the EU-10 and the United States for the market economy matches the growth differential for the total economy over the 1995–2009 period, with US TFP growing at twice the rate of the EU-10. The subsequent rows replicate the industry breakdown of van Ark et al. (2008): the production of ICT goods and services, goods-producing industries, and market services. Market services, in turn, are further split into distribution and trade industries, finance and business services, and personal services. The final two columns, which show the contribution of each industry grouping to market economy TFP growth, shows that the contributions from ICT production exactly match the aggregate growth. In other words, the net contribution of all industries other than ICT production is zero. Furthermore, the larger contribution from ICT production in the United States can be traced to faster TFP growth, not a larger ICT sector.¹¹

Despite a net difference of zero, the table does point to some similarities and differences compared with earlier analyses. Most important, TFP growth in goods-producing industries in the EU-10 is positive, while TFP declined in the United States. This can mostly be traced to TFP declines in construction, but also to slower TFP growth in manufacturing outside ICT production. Conversely, the United States had a clear TFP growth advantage in market services, mostly because of faster TFP growth in distribution and trade. This has often been linked to the intensity with which this sector uses ICT, as in Stiroh (2002) and Jorgenson et al. (2005). However, the fact that finance and business services show an overall negative contribution, despite ICT-use being most intensive in that sector, suggests the limitations of that view. Furthermore, the earlier focus on growth differences in market services (e.g., Inklaar et al. 2008) still seems relevant with today's numbers, but some of the US productivity growth advantage in this sector has disappeared over time. In part, this is due to the period chosen, with the earlier analysis based on data for the 1995–2004 period. But data revisions play an important role as well: in Inklaar et al. (2008), US TFP growth in market services was an annual average of 1.3%, but based on the current vintage of productivity data, growth only averaged 0.8% between 1995 and 2004.

22.2.1. Summing Up

This section on the transatlantic productivity growth gap has illustrated some of the strengths, but also the limitations of industry-level analysis for the diagnosis of aggregate growth differences. When specific industries are particularly dynamic, which has clearly been the case for the ICT production sector, it is important to isolate its role from that of other industries. Ever since the early studies of the US productivity growth resurgence (e.g., Gordon 2000; Jorgenson and Stiroh 2000; Oliner and Sichel 2000), it has been clear that the ICT sector has played a notable role, and it has also long been clear that the growth benefits from this sector have been smaller in Europe (Timmer et al. 2010). Some of the other diagnoses have been subject to greater variability over time, though. The role of ICT use seemed at one point to be quite important, suggesting (p. 732) possible productivity spillovers from this technology. But the fact that in finance and business services, among the most ICT-intensive industries of the economy, US TFP growth has been revised from strongly positive to clearly negative suggests that caution is in order.¹² This is even more pressing when making international growth comparisons, since price and volume measurement practices differ considerably across countries (Inklaar et al. 2008).

22.3. The Industry Sources of Convergence

Recent literature has focused on the role of industry productivity in shaping cross-country income differences and the importance of structural change for aggregate outcomes.¹³ However, most studies in this area give a comprehensive coverage of industries only for Organisation for Economic Co-operation and Development (OECD) countries. This begs the question of whether rich-country results are applicable to emerging economies as well. Alternatively, studies covers a wide range of countries, but only for a specific sector of the economy, such as agriculture or manufacturing.¹⁴ This begs the question of whether a specific sector truly plays an exceptional role in explaining cross-country differences in economic performance. In particular, the recent work of Rodrik (2013) suggests that productivity in manufacturing converges across countries, regardless of country factors (i.e., unconditional convergence). In this section, I will give a comprehensive accounting of changes in market economy productivity dispersion into the role of several major sectors of the economy for 38 economies that span much of the development spectrum.

22.3.1. Methodology

The crucial input for the analysis of convergence consists of estimates of relative industry productivity. Though there are clear parallels between the comparison of productivity

growth over time and productivity levels across countries, there are sufficient differences in methodology and data to warrant further discussion. Here I give an overview, drawing on the more detailed exposition in Inklaar and Diewert (2016).

To analyze the degree of convergence toward the productivity frontier, it is necessary to measure output and input levels that are comparable across countries and over time. It is also useful to have measures that are invariant to the choice of a reference point—that is, a single country and year that act as a basis for comparison for all other countries and years. Finally, it is useful to have a methodology that is based on an economic approach to production theory. Such an approach was developed by Caves, Christensen, and Diewert (1982a) (hereafter CCD), but their approach has a (p. 733) significant limitation. Their approach relies on the distance function methodology for aggregating inputs and outputs that can be traced back to Malmquist (1953), which they further developed (CCD 1982a). The problem is that this distance function methodology does not allow us to compare real GDP or real value added across countries, as that methodology requires a strict separation of outputs and inputs. Net output aggregates based on distance function techniques do not work if the output aggregate includes intermediate inputs or imports. In this section, we show how this problem can be addressed in a production theory framework by using the methodology that was developed by Diewert and Morrison (1986), drawing also on the techniques used by CCD.

We give a brief explanation of the methodology developed by Diewert and Morrison (1986) for a comparison of real outputs, inputs, and productivity levels across two time periods or two production units in the same industry. Consider a set of production units that produce a vector of M net outputs,¹⁵ $y \equiv [y_1, \dots, y_M]$, using a non-negative vector of N primary inputs, $x \equiv [x_1, \dots, x_N]$. Let the feasible set of net outputs and primary inputs for production unit i be denoted by S^i for $i = 1, \dots, I$. It is assumed that each S^i is a closed convex cone in R^{M+N} so that production is subject to constant returns to scale for each production unit. For each strictly positive net-output price vector $p \equiv [p_1, \dots, p_M] \gg 0_M$ and each strictly positive primary-input vector $x \gg 0_N$, define the *value added function* or *GDP function* for production unit k , $g^k(p, x)$, as follows:

$$g^i(p, x) \equiv \max_y \left\{ \sum_{m=1}^M p_m y_m : (y, x) \in S^i \right\}, \quad i = 1, \dots, I.$$

(22.4)

These value-added functions g^i provide a dual representation of the technology sets S^i under our assumptions on the technology sets. Finally, Diewert and Morrison assume specific functional forms for the value-added functions g^i defined by (22.1): they assumed that each value-added function has a translog functional form. Armed with these assumptions, Diewert and Morrison (1986, 661–665) were able to construct output, input, and productivity levels between any two production units using the economic approach to index number theory and Törnqvist-Theil (1967, 136–137) output price and input quantity indexes.

Given this starting, we can detail the methodology for comparing industry productivity level across countries and over time. We assume that there are four sets of basic data, each for $k = 1, \dots, K$ countries and $t = 1, \dots, T$ years. (i) The *value of net output* m in country k in domestic currency during period t is v_{ktm} for $m = 1, \dots, M$. Thus there are M net output commodities, and if $v_{ktm} < 0$, commodity m is used as an input by country k in period t . (ii) The *price or purchasing power parity (PPP)* in domestic currency for net output m in country k for time period t is $p_{ktm} > 0$. These output prices or PPPs are prices that use the same unit of measurement for the same commodity across countries. (iii) The *value of primary input* n in country k in domestic currency during period t is $V_{ktn} > 0$ for $n = 1, \dots, N$. (iv) The *price or PPP* (in domestic currency) for primary input n in country k for time period t is $w_{ktn} > 0$ for $n = 1, \dots, N$.

(p. 734) Given the preceding primary data sets, we can construct implicit output and input quantities for each country and each time period. Define the *implicit quantity* (or volume) y_{ktm} of net output as $y_{ktm} \equiv v_{ktm} / p_{ktm}$ and define the *implicit quantity* (or volume) x_{ktn} of primary inputs as $x_{ktn} \equiv V_{ktn} / w_{ktn}$. Define the *total value added* in domestic currency for country k in period t , v_{kt} , and the *total value of primary inputs* for country k in period t , V_{kt} , by summing over net outputs and inputs:¹⁶

$$v_{kt} \equiv \sum_{m=1}^M v_{ktm}; \quad V_{kt} \equiv \sum_{n=1}^N V_{ktn}; \quad k = 1, \dots, K; \quad t = 1, \dots, T.$$

(22.5)

In what follows, we will make use of *value-added output shares* $s_{ktm} \equiv v_{ktm} / v_{kt}$ and *primary-input cost shares* $S_{ktn} \equiv V_{ktn} / V_{kt}$.

Define the (strictly positive) net output price vector for country k in period t as $p_{kt} \equiv [p_{kt1}, \dots, p_{ktM}]$ and the corresponding net output quantity vector as $y_{kt} \equiv [y_{kt1}, \dots, y_{ktM}]$. Then under our assumptions on technology and behavior, Diewert and Morrison (1986, 665) have showed that the aggregate price of real value added in country k in period t relative to the aggregate price of real value added in country j in period s , $P_{kt/js}$, is equal to the Törnqvist-Theil output price index $P_T(p_{js}, p_{kt}, y_{js}, y_{kt})$; that is,

$$P_{kt/js} \equiv P_T(p_{js}, p_{kt}, y_{js}, y_{kt}) \equiv \exp \left[\sum_{m=1}^M \frac{1}{2} (s_{jsm} + s_{ktm}) \ln(p_{ktm} / p_{jsm}) \right]$$

(22.6)

Diewert and Morrison (1986, 665) also indicated that the corresponding implicit quantity index, $Y_{kt/js}$, provides a good estimator of the ratio of real value added in country k in period t relative to the real value added of country j in period s ; that is, we have

$$Y_{kt/js} \equiv [v_{kt} / v_{js}] / P_T(p_{js}, p_{kt}, y_{js}, y_{kt})$$

(22.7)

Obviously, we could pick a country and a time period (say period 1 and country 1) and treat this production unit as a numeraire unit and measure the GDP output prices and quantities of other observations relative to this numeraire unit. This would lead to a sequence of aggregate prices, $P_{kt/11}$, and quantities, $Y_{kt/11}$. However, we could just as easily pick country 2 in period 1 as the numeraire country, and this would lead to the sequence of country PPPs and real value added of $P_{kt/21}$ and $Y_{kt/21}$. Unfortunately, $P_{kt/21}$ will not, in general, be proportional to $P_{kt/11}$ and $Y_{kt/21}$ will not be proportional to $Y_{kt/11}$; that is, the results will depend on the choice of the numeraire country. CCD solved this numeraire dependence problem by averaging over all possible choices of the numeraire observation. Following this strategy, we use the Diewert-Morrison PPPs as the basic bilateral building blocks, rather than the CCD bilateral choice of index number formula, which did not allow for negative net outputs. Thus define the *geometric mean of all the PPP parities* for country k in time period t relative to all possible choices j, s of the base country, P_{kt*} as follows:

$$P_{kt*} \equiv \left[\prod_{j=1}^K \prod_{s=1}^T P_{kt/js} \right]^{\frac{1}{KT}}.$$

(22.8)

(p. 735) It is usually convenient to pick out the country with the largest economy (say country 1) in period 1 and form a set of normalized aggregate output PPPs that compare the PPPs defined by (22.9) or (22.11) to the PPP for country 1 in period 1. Thus we define our final set of *value-added output deflators*, P_{kt} , as follows:

$$P_{kt} \equiv P_{kt*} / P_{11*}.$$

(22.9)

The final set of *real value-added estimates* Y_{kt} that are comparable across time and space is defined by deflating each country's nominal value added by the PPPs defined by (22.9):¹⁷

$$Y_{kt} \equiv [v_{kt} / P_{kt}]$$

(22.10)

We next turn our attention to the problems associated with measuring real primary input across countries. Define the (strictly positive) *input quantity vector* as $x_{kt} \equiv [x_{kt1}, \dots, x_{ktN}]$ and the corresponding *input price vector* as $w_{kt} \equiv [w_{kt1}, \dots, w_{ktN}]$. Then under our assumptions on technology and behavior, Diewert and Morrison (1986, 665) showed that the aggregate quantity of primary input in country k in period t relative to the aggregate quantity of primary input in country j in period s , $X_{kt/js}$, is equal to the Törnqvist-Theil input quantity index $Q_T(w_{js}, w_{kt}, x_{js}, x_{kt})$; that is, we have

$$X_{kt/js} \equiv Q_T(w_{js}, w_{kt}, x_{js}, x_{kt}) \equiv \exp \left[\sum_{n=1}^N \frac{1}{2} (S_{jsn} + S_{ktn}) \ln(x_{ktn} / x_{jsn}) \right].$$

(22.11)

As was the case with the construction of output aggregates, there are KT different choices of a base country, and so we follow the same strategy of taking a geometric average of these alternative choices of a base observation. Thus define X_{kt^*} as

$$X_{kt^*} \equiv \left[\prod_{j=1}^K \prod_{s=1}^T X_{kt/js} \right]^{\frac{1}{KT}}.$$

(22.12)

We follow the same convention as on the output side to define a set of *input-quantity aggregates*, X_{kt} relative to country 1 in year 1 as¹⁸

$$X_{kt} \equiv V_{11} X_{kt^*} / X_{11^*}$$

(22.13)

Diewert and Morrison (1986, 663) showed that under their assumptions, a theoretical productivity index¹⁹ between the production unit k at period t relative to the production unit j at period s , $\Gamma_{kt/js}$, was equal to the output ratio $Y_{kt/js}$ defined by (22.7) divided by the input ratio $X_{kt/js}$ defined by (22.11); that is, we have

$$\Gamma_{kt/js} \equiv Y_{kt/js} / X_{kt/js}$$

(22.14)

As before, the bilateral productivity indexes defined by (22.14) are not transitive, and so they are made transitive by defining the ratio of the productivity of country k in period t to the geometric mean of all country TFP levels over all years, Γ_{kt^*} , as follows:²⁰

(p. 736)

$$\Gamma_{kt^*} \equiv \left[\prod_{j=1}^K \prod_{s=1}^T \Gamma_{kt/js} \right]^{\frac{1}{KT}} = Y_{kt^*} / X_{kt^*}$$

(22.15)

The Γ_{kt^*} are analogs to the translog *multilateral productivity indexes* defined by CCD (1982a, 81). Again, for ease of interpretation, we replace the productivity levels defined by (11.22) by the following *normalized productivity levels* Γ_{kt} :

$$\Gamma_{kt} \equiv [Y_{kt^*} / X_{kt^*}] / [Y_{11^*} / X_{11^*}] = Y_{kt} / X_{kt}$$

(22.16)

where Y_{kt} is defined by (22.10) and X_{kt} is defined by (22.13); that is, the KT normalized TFP levels, Γ_{kt} , defined by (22.16) are equal to the corresponding normalized output level Y_{kt} divided by the corresponding normalized input level X_{kt} .

The Industry Sources of Productivity Growth and Convergence

This completes the exposition of our methodology for making cross-country comparisons of output, input, and productivity using the economic approach to index number theory when the output aggregate contains intermediate inputs. To determine whether the degree to which productivity levels differ, it is useful to, first, consider how to measure the level of “world” productivity²¹ in each time period t . We define the world productivity level at time period t as the ratio of world output to world input, thus requiring a definition of world output and input. The multilateral output indexes, Y_{kt} defined by (22.10), are comparable across countries and time periods. Hence, it is meaningful to add them up to obtain aggregate measures of real output. Thus define *world output*, Y_t , as follows:

$$Y_t \equiv \sum_{k=1}^K Y_{kt}$$

(22.17)

In a similar fashion, *world input*, X_t , is defined as the sum of the multilateral input aggregates X_{kt} defined by (22.13):

$$X_t \equiv \sum_{k=1}^K X_{kt}$$

(22.18)

Define the country k share of world real input during period t , ω_{kt} , as

$$\omega_{kt} \equiv X_{kt} / \sum_{j=1}^K X_{jt}$$

(22.19)

Finally, the level of *world productivity*, Γ_t , is defined as the ratio of world output to input. It is then straightforward to show that Γ_t is equal to an input-share-weighted average of the multilateral productivity indexes Γ_{kt} over all countries k for time period t :

$$\Gamma_t \equiv Y_t / X_t = \sum_{k=1}^K \omega_{kt} \Gamma_{kt}$$

(22.20)

To assess the degree of convergence, I consider the dispersion of country productivity levels around world productivity levels. This is more commonly known as σ -convergence (p. 737) (see Lichtenberg 1994 and Barro 2015). This can be seen as the productivity counterpart to measures of cross-country income inequality (Milanovic 2012), showing to what extent productivity levels are becoming more similar over time. We define the following input-weighted measure of productivity dispersion as

$$\sigma_t \equiv \left[\sum_{k=1}^K \omega_{kt} \ln(\Gamma_{kt} / \Gamma_t)^2 \right]^{1/2}.$$

(22.21)

Note that Γ_{kt}/Γ_t is the ratio of the productivity level of country k in period t to world average level of productivity in period t . If all country productivity levels are the same in period t , each Γ_{kt} will be equal to Γ_t and σ_t will be equal to 0; that is, there is complete productivity convergence.

22.3.2. Data

The approach to estimating industry productivity levels discussed in the previous section requires data on the input-output structure of each country over time and data on relative prices that can be used to infer relative industry output prices and input prices. For information on country input-output structures, I make use of the World Input-Output Database (WIOD). This is a source of harmonized input-output tables, covering 35 industries and 40 countries for the period 1995–2011. For our analysis, we omit Luxembourg and Indonesia due to data challenges. Still, the remaining 38 countries represent two-thirds of the world population and over 80% of world GDP and span much of the development spectrum, from India to the United States.

The construction and features of the WIOD are described in detail in Timmer, Dietzenbacher, Los, Stehrer, and de Vries (2015). The WIOD is constructed based on national supply and use tables (SUTs), combined with time series data from country National Accounts to ensure consistency with trends in industry output and overall economic activity. Importantly for analysis of global value chains, the SUTs are combined with data on trade in goods and services. This way, it is possible to distinguish the composition of intermediate inputs not only in terms of *what* products are used, but also *where* these products are produced and, in many cases, imported from. For the purposes of this chapter, though, this level of detail is not necessary, as only a distinction between domestically produced and imported intermediate inputs (from any country) is needed. Still, the fact that much effort has gone into harmonizing the industrial classifications across countries makes the WIOD ideally suited for this type of cross-country analysis.

The input-output data from WIOD include the net output and factor input values, the v_{ktm} and V_{ktm} . We additionally need information on relative prices to allow for comparisons of output and factor inputs, that is, the p_{ktm} and w_{ktm} . In part, these are drawn from the Socio-Economic Accounts (SEA) of WIOD. These provide information on the labor compensation and number of hours worked by workers who are (p. 738) high-skilled, medium-skilled, and low-skilled (based on their level of education) as well as on capital stocks.²²

For computing prices of industry output (and hence domestically produced intermediate inputs), relative prices for consumption and investment are used. Consumption and investment prices are from the International Comparison Program (ICP), run by the World Bank, and we use the three surveys covering a global sample of countries that were done in the 1995–2011 period, namely for 1996, 2005, and 2011.²³ We use the most detailed publicly available data from each of these years and map consumption and

investment categories to industries. Aggregating across expenditure categories is done using the CCD index. ICP prices are based on surveys of purchaser prices rather than producer prices, which means that differences in product taxes and distribution margins would lead to a bias in industry output prices. I therefore use tax and margin data from WIOD to adjust the ICP prices.²⁴ For years not covered by ICP survey data, we use industry deflators to interpolate (for, say, 2007) or extrapolate (e.g., 1995) relative prices, as in Feenstra, Inklaar and Timmer (2015).

For three of the services industries—government, health, and education—the ICP prices do not reflect the prices paid by purchasers of these services, since public provision or funding makes output prices hard or even impossible to observe. Instead, ICP aims to measure input prices (see Heston 2013). In our framework, this implies equal productivity levels across countries since relative “output” prices equal relative input prices. These industries are therefore excluded when analyzing productivity differences over time, just as they were in the previous section on growth differences. Similarly, the real estate industry is excluded, as (for the most part) its output is the imputed rental cost of owner-occupied housing, and the “private households with employed persons” industry is excluded as its dominant (sometimes only) input is labor (as well as incomplete coverage across countries). The remaining set of 30 industries will be referred to as the market economy.

In contrast to other industries, there is direct data on producer prices in agriculture, from the Food and Agricultural Organization (FAO). These have been widely used in studying productivity in agriculture, typically based on the relative prices estimated by Rao (1993).²⁵ For this analysis, I collected prices and production quantities for crops and livestock directly from FAO and aggregated these to overall agriculture relative output prices for each year using the CCD index.

The relative price of capital—estimated using equation (22.8)—requires data on investment prices, for which ICP prices can be used directly. The required rate of return is taken as the lending rate, taken from the International Monetary Fund (IMF) International Financial Statistics; the depreciation rates are from Penn World Table version 8.1, which provides country-level average depreciation rates in each year; and the investment price change is from WIOD. One drawback is that relative investment prices cover only fixed reproducible assets, thus omitting land. This omission can be particularly relevant for agriculture, so I also computed relative productivity using the procedure of Vollrath (2009). The results for cross-country differences in agricultural productivity over time are qualitatively similar to those presented in the following. (p. 739)

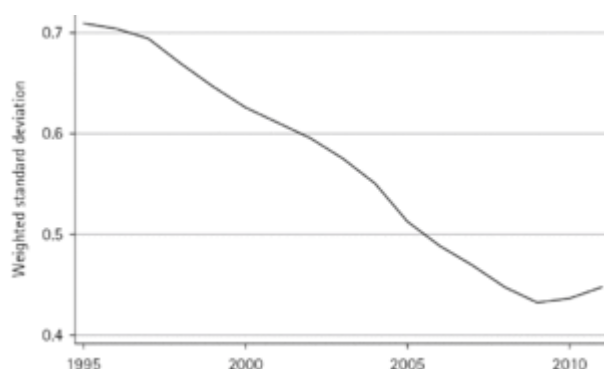
22.3.3. Results

To frame the context of the sectorial analysis, Figure 22.3 presents the trend in market economy productivity dispersion across the set of 38 countries covered in the analysis. As discussed earlier, the market economy refers to the aggregate of all industries except

The Industry Sources of Productivity Growth and Convergence

government, health and education, real estate, and households. Each country's (log) productivity level is multiplied by the share of factor inputs to give greater weight to (e.g.) China and less to (e.g.) Cyprus; see equation (2.21). The figure shows a substantial and fairly steady decline in the standard deviation, so that in 2011 it is 37% lower than it was in 1995.

Aggregate convergence is also found if weighting is omitted (-21%). Furthermore, the 38% decline in Figure 22.1 is both economically substantial and, using the T^3 test of Carree and Klomp (1997), statistically significant at the 10% level. Figure 22.3 also shows that the finding of convergence is a fairly continuous process, so the subsequent comparison will be done by comparing the dispersion in 2011 to that in 1995. Aggregate convergence is due in part to rapidly rising productivity levels in China (increasing from 18% to 40% of the 1995 US level) and India (39% to 45%). However, big increases in productivity are also seen in Turkey (38% to 49%) and in Central and Eastern Europe, in countries like Estonia (27% to 39%) and Poland (30% to 64%).



[Click to view larger](#)

Figure 22.3 Market economy productivity dispersion, 1995–2011.

Notes: Productivity dispersion is measured as the standard deviation of log productivity levels, weighted using the share of each country in global factor inputs. Market economy covers all industries except government, health, education, real estate, and households.

To analyze the sectorial pattern of convergence and how these contribute to aggregate convergence, I split the market economy into a traded and non-traded sector, where the traded sector encompasses agriculture, mining, and manufacturing, and the non-traded sector covers utilities, construction, and (market) services.

Alternatively, I consider a split into the more traditional major sectors, distinguishing agriculture,

manufacturing, (p. 740) market services (transport, distribution, communication, hotels and restaurants, finance and business services), and other goods (mining, utilities, and construction). Table 22.2 summarizes this analysis and shows that productivity convergence is driven primarily by convergence in the traded sector. The major sector distinction shows that manufacturing and other goods showed notable convergence, with smaller declines in dispersion in agriculture and, particularly, market services.

The Industry Sources of Productivity Growth and Convergence

Table 22.2 Productivity Dispersion in 1995 and 2011 by Main Sectors

	1995	2011	% Change	
Market economy	0.709	0.448	-37	*
Traded sector	1.144	0.871	-24	*
Non-traded sector	0.373	0.347	-7	
Agriculture	0.822	0.703	-14	
Manufacturing	1.161	0.920	-21	
Market services	0.437	0.413	-5	
Other goods	0.328	0.233	-29	*

Notes: Table reports the standard deviation of log productivity levels, weighted using country shares in factor inputs.

(*) indicates that the indicated change is significant at the 10% level according to the T^3 test of Carree and Klomp (1997).

Convergence analyses for OECD countries have typically shown that productivity in services converges more rapidly than manufacturing productivity; this was the main result of Bernard and Jones (1996), and van Biesebroeck (2009) has similar findings. In contrast, the study of manufacturing productivity for a much broader set of countries by Rodrik (2013) showed clear evidence of convergence. The results in Table 22.2 suggest that the convergence of productivity in services in OECD countries is specific to that group of countries or to the time period, rather than a more general result.²⁶ The sizable productivity dispersion in agriculture is consistent with the broader literature (e.g., Caselli 2005) and the relative lack of convergence in this sector shows that this large dispersion is a persistent factor.

22.3.4. Summing Up

Compared with the earlier analysis of the transatlantic growth gap, which came in a line of studies of industry productivity growth, this industry perspective on productivity convergence is a much less well-trodden path. As before, the analysis here plays, in (p. 741) part, a diagnostic role: Which industries are driving aggregate productivity convergence in this sample of countries? However, by confirming the result of Rodrik (2013) that manufacturing plays an important role in aggregate convergence, this analysis increases support for policies that aim to strengthen the role of manufacturing in the economy.

22.4. Determinants of Productivity Growth and Convergence

Given an increased understanding of the role of different sectors in aggregate convergence, it is useful to find potential determinants of productivity growth and, ideally, to better understand why convergence is stronger in some sectors and industries than in others. The differences in convergence shown in Table 22.2 are magnified when analyzing individual industries or countries. In the median industry, productivity dispersion decreased by 21%, similar to the market economy rate, but productivity dispersion in the textiles and wearing apparel industry decreased by 58%, while productivity dispersion in air transport increased by 24%. Indeed, 6 out of 30 industries showed divergence rather than convergence. Also, countries that show larger increases in their aggregate relative productivity levels tend to have more industries with increasing productivity levels, but the correlation is low at 0.09. This raises the question of what could be driving these differences.

To answer this question, I use the following general model used broadly in the “Schumpeterian” growth literature (Aghion et al. 2014):²⁷

$$\Delta \ln \left(\frac{A_{ict}}{A_{ict-1}} \right) = \beta_1 \ln \left(\frac{A_{ict-1}}{A_{it-1}^F} \right) + \beta_2 X_{ict-1} + \beta_3 X_{ict-1} \times \ln \left(\frac{A_{ict-1}}{A_{it-1}^F} \right) + \eta_{ic} + \eta_t + \epsilon_{ict}$$

(22.22)

In this equation, productivity growth for industry i in country c from year $t - 1$ to year t is explained using the proximity to the productivity frontier—the productivity level in country c relative to the productivity level of the country with the highest productivity level at $t - 1$, explanatory variable X and an interaction between X and the proximity to the productivity frontier.²⁸ In addition, a full set of country-industry dummies and year dummies is included. We would expect a negative coefficient for β_1 , since a greater proximity to the productivity frontier implies fewer opportunities to achieve productivity growth by imitating frontier technologies.

The main interest is in coefficient β_3 . If this coefficient is significantly different from zero, it implies that variable X has a different effect on productivity growth depending on the proximity to the productivity frontier. So, for example, Griffith et al. (2004) find that in countries that are closer to the frontier, research and development (R&D) spending contributes less to productivity growth, indicating that R&D spending helps both innovation (pushing out the frontier) and imitation (catching up to the frontier). (p. 742)

Table 22.3 Potential Determinants of Productivity Growth

Variable	Definition	Effect on Convergence	Source
High-skilled	The share of university-educated workers in total hours worked	– (Vandenbussche et al. 2006)	WIOD, SEA
High-tech M	Industry imports of intermediate inputs of chemicals, machinery, electronics, and transport equipment as a share of industry gross output	+ (Keller, 2004)	WIOD
R&D	Business enterprise research and development expenditure as a share of industry gross output	+ (Griffith et al. 2004)	OECD, Eurostat
FDI	Stock of inward foreign direct investment as a share of gross output	+ (Keller, 2004)	OECD, Eurostat

The Industry Sources of Productivity Growth and Convergence

Lerner	Ratio of price over marginal cost	+ (Aghion et al. 2014)	INDICSER database
--------	-----------------------------------	------------------------	-------------------

Note: WIOD, see www.wiod.org; INDICSER, see www.indicser.com. The (hypothesized) effect on convergence is positive if a higher value would lead to faster growth in industries that are farther from the frontier (or slower growth in industries close to the frontier).

Table 22.3 defines and describes the set of *X*-variables that are considered in the analysis. The first is the share of hours worked by high-skilled workers which, according to Vandenbussche et al. (2006), should contribute positively to productivity growth only in settings of close proximity to the frontier since more high-skilled workers would stimulate the rate of innovation.²⁹ The second is the share of high-tech imports. As the survey of Keller (2004) discusses, imports of more advanced inputs are an important source of technology transfer, so these imports would be expected to have a greater impact on productivity growth for industries that are farther from the productivity frontier.³⁰ Note that “high-tech” uses the OECD definition of high and medium-high technology industries. The third variable is R&D, which according to Griffith et al. (2004) would have a greater impact in industries farther from the productivity frontier since R&D helps both innovation and imitation. The fourth variable is foreign direct investment (FDI), which—again—following Keller (2004) could be a source of foreign technology and thus help growth in industries more distant from the frontier.³¹ The final variable is the Lerner index, or price-cost margin, where a higher Lerner index implies less intensive competition. As discussed in Aghion et al. (2014), fiercer competition (so a lower Lerner index) would be particularly beneficial for industries close to the frontier, as those industries rely more on innovation for growth and (unless competition turns too cut-throat) competition is beneficial for growth.³²

Given these predictions, equation (22.11) can be estimated for each of the variables of interest. As indicated in the equation, the regressions include dummies for each country/industry pair to account for unobserved heterogeneity and year dummies to account for common shocks. In addition, I use two further lags of the explanatory variables (so at $t - 2$ and $t - 3$) as instruments in a two-step Generalized Method of Moments procedure to reduce endogeneity concerns. Though more truly exogenous variables, such as the introduction of the European Single Market Program exploited by Griffith et al. (2010), would be preferable, these are typically hard to find. Finally, standard errors are clustered by country-industry pair to allow for correlation of errors within each cross-section.

Table 22.4 shows the results of the analysis. The first row shows industries that are closer to the productivity frontier grow less rapidly, though in the more limited samples for R&D (mostly manufacturing and omitting some emerging economies) and FDI (omitting some emerging economies) these are less significant. In the final column, the coefficient is not significantly different from zero and the sample covers only eight European economies

after 2002. Turning to the explanatory variables, the table shows that high-tech imports, R&D, and FDI have a significant positive effect on productivity growth. This is a useful confirmation of the literature in these areas. Furthermore, given that high-tech imports and R&D are more important in manufacturing, and even more (p. 744) so in ICT manufacturing, these factors will clearly be important, whether in trying to close the transatlantic growth gap (Ortega-Argilés, 2012) or more broadly. However, these effects do not vary depending on the proximity to the productivity frontier. In fact, none of the interaction coefficients is significantly different from zero, thus failing to contribute to our understanding of why some industries show faster convergence than others.

The Industry Sources of Productivity Growth and Convergence

Table 22.4 Explaining Productivity Growth and Convergence: Regression Results

	(1)	(2)	(3)	(4)	(5)
	High-Skilled	High-Tech M	R&D	FDI	Lerner
Proximity to the frontier	-0.0279***	-0.0334***	-0.0174*	-0.0185*	0.0369
	(0.00765)	(0.00755)	(0.00957)	(0.0108)	(0.0310)
Explanatory variable	-0.00123	0.162***	0.852***	0.00259**	-0.101
	(0.0386)	(0.0582)	(0.329)	(0.00103)	(0.201)
Interaction	-0.0276	0.0663	-0.478	-0.00283	-0.279
	(0.0338)	(0.0430)	(0.395)	(0.00254)	(0.216)
Observations	13,435	13,435	5,676	4,398	1,955
Overid. restrictions	0.727	0.404	0.129	0.197	0.0482

The Industry Sources of Productivity Growth and Convergence

Notes: Each column represents a separate regression explaining productivity growth using the proximity to the productivity frontier, the explanatory variable that is identified in the column header and an interaction between the proximity to the frontier and the explanatory variable; see also equation (22.8) for the specification and Table 22.3 for definitions of the explanatory variables. Each regression includes country-industry dummies and year dummies and two lagged values of the independent variables are used as instruments in a two-step GMM procedure. Standard errors, clustered by country-industry pair, are in parentheses. “Overid. restrictions” gives the p -value of the Hansen J statistic on the overidentifying restrictions of all instruments.

(***) $p < 0.01$,

(**) $p < 0.05$,

(*) $p < 0.1$.

If the results had shown that a particular variable had a stronger effect on productivity growth for industries farther from the frontier, this would have been clear evidence that this variable enhances the rate of convergence. A more indirect way would be if that variable has a direct effect on productivity growth and takes on higher values in industries farther from the frontier. The high-tech import share is negatively correlated with the proximity to the frontier but at -0.04 , the relationship is weak. In contrast, R&D intensity is positively correlated with proximity to the frontier and, at 0.11 , this relationship is somewhat stronger. So, if anything, the high-tech import share is a force of convergence, while R&D would lead to divergence. However, it is unclear whether these correlations have systematic drivers or are a coincidence.

To establish the robustness of the results in Table 22.4, I have considered that the industry proximity to the frontier could be measured with error and that, due to the persistence in this variable, this is not adequately addressed by using lagged values of industry proximity. In the first sensitivity analysis, I therefore use two lagged values of the aggregate proximity to the productivity frontier as instruments for industry proximity to the frontier. These are clearly weaker instruments, as indicated by first-stage F -statistics, and the pattern of results is the same.

In the second sensitivity analysis, I run the regressions for major sectors (i.e., subsets of industries, rather than all industries together). Specifically, I run regressions for manufacturing, market services and other goods (including agriculture, as well as mining, utilities, and construction). This provides some evidence that the impact of FDI varies with proximity to the frontier, but it is unclear why FDI would have a stronger effect on productivity growth when an industry is close to the productivity frontier in manufacturing and other goods production, but a weaker effect in market services.

22.4.1. Summing Up

The aim of this section was to establish why some industries show more rapid growth and convergence than others by testing whether a variety of variables have an effect on productivity growth and whether this effect differs in industries that are more distant from the productivity frontier. While some variables—R&D, FDI, and high-tech imports intensity—were indeed significantly related to productivity growth, others—high-skilled workers and competition—were not. More important, none of the variables showed a significantly different effect on productivity growth depending on the proximity to the productivity frontier.

(p. 745) So where should one look to better understand productivity convergence? It could be that the specification chosen here is not appropriate; for instance, it could be that learning takes place in proportion to actual trade or investment between specific countries (e.g., Keller 2004) instead of a common rate of learning from the frontier industry. Beyond that, a first set of alternative candidates are sector- or industry-specific regulations, such as import tariffs and other trade restrictions (e.g., Lileeva and Trefler

2010) or barriers to entry (Nicoletti and Scarpetta 2003). Other candidates are macro-level variables whose effects differ across industries, such as financial development (Rajan and Zingales 1998), infrastructure (Fernald 1999), or labor market institutions (Bassanini, Nunziata, and Venn 2009). A third possibility would be that a variable considered here has a different effect depending on some other variable that is related to, but not perfectly correlated with, (industry) productivity. For example, Alfaro et al. (2010) find that FDI has a larger effect on productivity in countries with a greater level of financial development.

22.5. Discussion and Conclusions

This chapter started with the question in which settings, industry-level productivity analysis has added value in the face of growing body of firm-level studies and academic and policy interest in economy-wide results. The aim of the three illustrations presented in this chapter has been to showcase not only some of strengths, but also the limitations, of industry-level productivity analysis. In terms of strengths, there is a clear role for industry-level analysis in diagnosing why overall (productivity) growth is faster in some countries than in others. As shown in the discussion of the transatlantic productivity growth, one may find that overall productivity growth is faster in one country than in another, but this can be for a multitude of reasons. And since firm-level analysis is typically not able to cover a considerable number of countries in a single study and because firm-level analysis typically does not cover all areas of the economy, industry-level analysis is the next best thing. In the case of productivity growth differences between the European Union and the United States, this showed that the United States gets most of its growth advantage for more rapid growth in the ICT production sector, but also that the productivity growth benefits from ICT use in the United States are less impressive or even absent compared to earlier vintages of the data. The other result is that distribution and trade is a sector where the European Union lags behind. This is an area where EU policy to strengthen the internal market may play an important role, as unified distribution systems and fewer restrictions on cross-border activity could lead to higher productivity. Though this is speculative, such a result can focus the attention of researchers and policymakers.

Similarly, in the broader cross-country setting, I strengthened the finding of Rodrik (2013) that convergence in manufacturing is a powerful force. My analysis has shown that this sector has made a clear contribution to the overall convergence of productivity (p. 746) among 38 major emerging and advanced economies. Finally, the analysis of the determinants of productivity growth has shown (again) the importance of R&D, FDI, and high-tech imports in fostering productivity growth. However, these play no systematic role in helping or hindering the pace of convergence. This means there is still a clear role for systematic industry-level analysis to better understand why, for example,

manufacturing productivity converges and what governments may do to speed this process along.

On the limitations side, the analysis of productivity growth in the European Union and the United States has shown how some growth differences have not proven robust to changing times and measurement practices. Especially in the area of financial and business services, it has long been known that measurement of prices, and thus productivity, is challenging. Furthermore, cross-country differences in measurement can confound cross-country comparisons. This can be a reason to stay away from such sectors in research, but the fact that these services industries represent a large and growing part of economic activity should, in my view, be a spur to improve our state of knowledge and measurement.

So what may be learned from future industry-level research, and how? Especially for understanding growth in services industries, the industry level remains a relevant platform—judging in part by the absence of much firm-level research in this area. Furthermore, this is also the area where some of the newer “sources of growth” may originate, as the source of “intangible assets,” such as new financial products, brand equity, and organization capital (Corrado and Hulten 2010). Understanding whether and how such assets contribute to growth requires a better understanding of these activities and how innovation takes place in, for example, management consulting. Beyond that, more careful consideration of how the regulatory environment has an impact on different industries in different countries remains important, especially in relation to policymakers.

References

- Adamopoulos, Tasso, and Diego Restuccia. 2014. “The Size Distribution of Farms and International Productivity Differences.” *American Economic Review* 104(6): 1667–1697.
- Aghion, Philippe, Ufuk Akcigit, and Peter Howitt. 2014. “What Do We Learn from Schumpeterian Growth Theory?” In *Handbook of Economic Growth*, edited by Philippe Aghion and Steven N. Durlauf, Vol. 2B, 515–563. Philadelphia: Elsevier.
- Alfaro, Laura, Areendam Chanda, Sebnem Kalemli-Ozcan, and Selin Sayek. 2010. “Does Foreign Direct Investment Promote Growth? Exploring the Role of Financial Markets on Linkages.” *Journal of Development Economics* 91: 242–256.
- Ang, James B., Jakob B. Madsen, and Md. Rabiul Islam. 2011. “The Effects of Human Capital Composition on Technological Convergence.” *Journal of Macroeconomics* 33: 405–476.
- Barro, Robert J. (2015). “Convergence and Modernisation” *Economic Journal* 125: 911–942.

The Industry Sources of Productivity Growth and Convergence

Bartelsman, Eric J., John Haltiwanger, and Stefano Scarpetta. 2013. "Cross-Country Differences in Productivity: The Role of Allocation and Selection." *American Economic Review* 103(1): 305–334.

Bassanini, Andrea, Luca Nunziata, and Danielle Venn. 2009. "Job Protection Legislation and Productivity Growth in OECD Countries." *Economic Policy* 24(58): 349–402.

Basu, Susanto, Luigi Pascali, Fabio Schiantarelli, and Luis Servén. 2014. "Productivity, Welfare and Reallocation: Theory and Firm-Level Evidence." NBER Working Paper No. 15579. <http://www.nber.org/papers/w15579>.

(p. 749) Bernard, Andrew B., and Charles I. Jones. 1996. "Comparing Apples to Oranges: Productivity Convergence and Measurement across Industries and Countries." *American Economic Review* 86(5): 1216–1238.

Bloom, Nicholas, Rafaela Sadun, and John van Reenen. 2012. "Americans Do IT Better: US Multinationals and the Productivity Miracle." *American Economic Review* 102(1): 167–201.

Cameron, Gavin, James Proudman, and Stephen Redding. 2005. "Technological Convergence, R&D, Trade and Productivity Growth." *European Economic Review* 49: 775–807.

Carree, Martin, and Luuk Klomp. 1997. "Testing the Convergence Hypothesis: A Comment." *Review of Economics and Statistics* 79: 683–686.

Caselli, Francesco. 2005. "Accounting for Cross-Country Income Differences." In *Handbook of Economic Growth*, edited by Philippe Aghion and Steven N. Durlauf, 679–741. Amsterdam: North-Holland.

Caves, Douglas W., Laurits R. Christensen, and W. Erwin Diewert. 1982a. "Multilateral Comparisons of Output, Input and Productivity Using Superlative Index Numbers." *Economic Journal* 92: 73–86.

Caves, Douglas W., Laurits R. Christensen, and W. Erwin Diewert. 1982b. "The Economic Theory of Index Numbers and the Measurement of Input, Output, and Productivity." *Econometrica* 50: 1392–1414.

Christensen, Laurits R., Dale W. Jorgenson, and Lawrence Lau. 1971. "Conjugate Duality and the Transcendental Logarithmic Production Function." *Econometrica* 39: 255–256.

Chandra, Amitabh, Amy Finkelstein, Adam Sacarny, and Chad Syverson. 2016. "Healthcare Exceptionalism? Productivity and Allocation in the U.S. Healthcare Sector." *American Economic Review* 106(8): 2110–2144.

The Industry Sources of Productivity Growth and Convergence

Cipollina, Maria, Giorgia Giovannetti, Filomena Pietrovito, and Alberto F. Pozzolo. 2012. "FDI and Growth: What Cross-Country Industry Data Say." *The World Economy* 35(11): 1599-1629.

Corrado, Carol A., and Charles R. Hulten. 2010. "How Do You Measure a 'Technological Revolution'?" *American Economic Review: Papers & Proceedings* 100(3): 99-104.

Diewert, W. Erwin, and Catherine J. Morrison. 1986. "Adjusting Output and Productivity Indexes for Changes in the Terms of Trade." *Economic Journal* 96: 659-679.

Duarte, Margarida, and Diego Restuccia. 2010. "The Role of the Structural Transformation in Aggregate Productivity." *Quarterly Journal of Economics* 125(1): 129-173.

Feenstra, Robert C., and John Romalis. 2014. "International Prices and Endogenous Quality." *Quarterly Journal of Economics* 129(2): 477-527.

Feenstra, Robert C., Robert Inklaar, and Marcel P. Timmer. (2015). "The Next Generation of the Penn World Table." *American Economic Review* 105(10): 3150-3382.

Fernald, John G. 1999. "Roads to Prosperity? Assessing the Link Between Public Capital and Productivity." *American Economic Review* 89(3): 619-638.

Fernald, John G., and Charles I. Jones. 2014. "The Future of U.S. Economic Growth." *American Economic Review* 104(5): 44-49.

Foster, Lucia, John Haltiwanger, and C. J. Krizan. 2006. "Market Selection, Reallocation, and Restructuring in the U.S. Retail Trade Sector in the 1990s." *Review of Economics and Statistics* 88(4): 748-758.

Foster, Lucia, John Haltiwanger, and Chad Syverson. 2008. "Reallocation, Firm Turnover, and Efficiency: Selection on Productivity or Profitability?" *American Economic Review* 98(1): 394-425.

Gollin, Douglas, David Lagakos, and Michael E. Waugh. 2014. "The Agricultural Productivity Gap." *Quarterly Journal of Economics* 129(2): 939-993.

(p. 750) Gordon, Robert J. 2000. "Does the 'New Economy' Measure up to the Great Inventions of the Past?" *Journal of Economic Perspectives* 14(4): 49-74.

Griffith, Rachel, Rupert Harrison, and Helen Simpson. 2010. "Product Market Reform and Innovation in the EU." *Scandinavian Journal of Economics* 112(2): 389-415.

Griffith, Rachel, Stephen Redding, and John van Reenen. 2004. "Mapping the Two Faces of R&D: Productivity Growth in a Panel of OECD Industries." *Review of Economics and Statistics* 86(4): 883-895.

The Industry Sources of Productivity Growth and Convergence

Herrendorf, Berthold, and Ákos Valentinyi. 2012. "Which Sectors Make Poor Countries So Unproductive?" *Journal of the European Economic Association* 10(2): 323–341.

Herrendorf, Berthold, Richard Rogerson, and Ákos Valentinyi. 2014. "Growth and Structural Transformation." In *Handbook of Economic Growth*, edited by Philippe Aghion and Steven N. Durlauf, Vol. 2B, 855–941. Amsterdam: Elsevier.

Heston, Alan. 2013. "Government Services: Productivity Adjustments," In *Measuring the Real Size of the World Economy*, edited by the World Bank. 413–440. Washington, DC: World Bank.

Hsieh, Chang-Tai, and Peter J. Klenow. 2009. "Misallocation and Manufacturing TFP in China and India." *Quarterly Journal of Economics* 124(4): 1403–1448.

Hulten, Charles R. 2010. "Growth Accounting." In *Handbook of the Economics of Innovation*, edited by Bronwyn H. Hall and Nathan Rosenberg, Vol. 2, 987–1031. Amsterdam: Elsevier/North Holland.

Inklaar, Robert. 2015. "Searching for Convergence and Its Causes: An Industry Perspective." In *The World Economy: Growth or Stagnation?*, edited by Dale W. Jorgenson, Kyoji Fukao, and Marcel P. Timmer, 508–534. Cambridge: Cambridge University Press.

Inklaar, Robert, and W. Erwin Diewert. 2016. "Measuring Industry Productivity and Cross-Country Convergence." *Journal of Econometrics* 191(2): 426–433.

Inklaar, Robert, and Marcel P. Timmer. 2009. "Productivity Convergence across Industries and Countries: The Importance of Theory-Based Measurement." *Macroeconomic Dynamics* 13(S2): 218–240.

Inklaar, Robert, and Marcel P. Timmer. 2014. "The Relative Price of Services." *Review of Income and Wealth* 60(4): 727–746.

Inklaar, Robert, Marcel P. Timmer, and Bart van Ark. 2008. "Market Services Productivity across Europe and the US." *Economic Policy* 23(53): 139–194.

Inklaar, Robert, and J. Christina Wang. 2011. "Real Output of Bank Services: What Counts Is What Banks Do, Not What They Own." *Economica* 80(317): 96–117.

Jorgenson, Dale W. 2005. "Accounting for Growth in the Information Age." In *Handbook of Economic Growth*, edited by Phillipe Aghion and Steven N. Durlauf, Vol. 1A, 743–815. Amsterdam: Elsevier/North Holland.

Jorgenson, Dale W., and Zvi Griliches. 1967. "The Explanation of Productivity Change." *Review of Economic Studies* 34: 249–283.

Jorgenson, Dale W., Mun S. Ho, and Kevin J. Stiroh. 2005. *Information Technology and the American Growth Resurgence*. Cambridge, MA: MIT Press.

Jorgenson, Dale W., and Kevin J. Stiroh. 2000. "Raising the Speed Limit: US Economic Growth in the Information Age." *Brookings Papers on Economic Activity* 1: 125–211.

Keller, Wolfgang. 2004. "International Technology Diffusion." *Journal of Economic Literature* XLII: 752–782.

Lagakos, David, and Michael E. Waugh. 2013. "Selection, Agriculture, and Cross-Country Productivity Differences." *American Economic Review* 103(2): 948–980.

(p. 751) Lichtenberg, Frank R. 1994. "Testing the Convergence Hypothesis." *Review of Economics and Statistics* 76(3): 576–579.

Lileeva, Alla, and Daniel Trefler. 2010. "Improved Access to Foreign Markets Raises Plant-Level Productivity . . . for Some Plants." *Quarterly Journal of Economics* 125(3): 1051–1099.

Malmquist, Sten (1953), "Index Numbers and Indifference Surfaces", *Trabajos de Estadística* 4, 209–242.

McMillan, Margaret S., and Dani Rodrik. 2011. "Globalization, Structural Change and Productivity Growth." In *Making Globalization Socially Sustainable*, edited by Mark Bachetta and Marion Jansen, 49–84. Geneva: International Labor Organization.

McMorrow, Kieran, Werner Röger, and Alessandro Turrini. 2010. "Determinants of TFP Growth: A Close Look at Industries Driving the EU-US TFP Gap." *Structural Change and Economic Dynamics* 21: 165–180.

Milanovic, Branko. 2012. "Global Inequality Recalculated and Updated: The Effect of New PPP Estimates on Global Inequality and 2005 Estimates." *Journal of Economic Inequality* 10: 1–18.

Nicoletti, Giuseppe, and Stefano Scarpetta. 2003. "Regulation, Productivity and Growth: OECD Evidence." *Economic Policy* 18(36): 9–72.

Oliner, Stephen D., and Daniel E. Sichel. 2000. "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives* 14(4): 3–22.

O'Mahony, Mary, and Marcel P. Timmer. 2009. "Output, Input and Productivity Measures at the Industry Level: The EU KLEMS Database." *Economic Journal* 119: F374–F403.

Ortega-Argilés, Raquel. 2012. "The Transatlantic Productivity Gap: A Survey of the Main Causes." *Journal of Economic Surveys* 26(3): 395–419.

Rajan, Raghuram G., and Luigi Zingales. 1998. "Financial Dependence and Growth." *American Economic Review* 88(3): 559–586.

Rao, D. S. Prasada. 1993. "Intercountry Comparisons of Agricultural Output and Productivity." FAO Economic and Social Development Paper No. 112. http://www.fao.org/fileadmin/templates/ess/ess_test_folder/World_Census_Agriculture/Publications/FAO_ESDP/ESDP_112_Intercountry_comparisons_of_agricultural_output_and_productivity.pdf.

Restuccia, Diego, Dennis Tao Yang, and Xiaodung Zhu. 2008. "Agriculture and Aggregate Productivity: A Quantitative Cross-Country Analysis." *Journal of Monetary Economics* 55: 234–250.

Rodrik, Dani. 2013. "Unconditional Convergence in Manufacturing." *Quarterly Journal of Economics* 128(1): 165–204.

Stiroh, Kevin J. 2002. "Information Technology and the US Productivity Revival: What Do The Industry Data Say?" *American Economic Review* 92(5): 1559–1576.

Syverson, Chad. 2011. "What Determines Productivity?" *Journal of Economic Literature* 49(2): 326–365.

Theil, Henri. 1967. *Economics and Information Theory*. Amsterdam: North Holland.

Timmer, Marcel P., Erik Dietzenbacher, Bart Los, Robert Stehrer, and Gaaitzen J. de Vries. 2015. "An Illustrated Guide to the World Input-Output Database: The Case of Global Automotive Production." *Review of International Economics* 23: 575–605.

Timmer, Marcel P., and Bart van Ark. 2005. "Does Information and Communication Technology Drive EU-US Productivity Growth Differentials?" *Oxford Economic Papers* 57: 693–716.

Timmer, Marcel P., Robert Inklaar, Mary O'Mahony, and Bart van Ark. 2010. *Economic Growth in Europe: A Comparative Industry Perspective*. Cambridge: Cambridge University Press.

(p. 752) Utar, Hale. 2014 "When the Floodgates Open: 'Northern' Firms' Response to Removal of Trade Quotas on Chinese Goods." *American Economic Journal: Applied Economics* 6(4): 226–250.

van Ark, Bart, Mary O'Mahony, and Marcel P. Timmer. 2008. "The Productivity Gap Between Europe and the United States: Trends and Causes." *Journal of Economic Perspectives* 22: 25–44.

Van Biesebroeck, Johannes. 2009. "Disaggregate Productivity Comparisons: Sectoral Convergence in OECD Countries." *Journal of Productivity Analysis* 32: 63–79.

Vandenbussche, Jérôme, Philippe Aghion, and Costas Meghir. 2006. "Growth, Distance to Frontier and Composition of Human Capital." *Journal of Economic Growth* 11: 97–127.

Vollrath, Dietrich. 2009. "How Important Are Dual Economy Effects for Aggregate Productivity?" *Journal of Development Economics* 88(2): 325–334.

World Bank. 2008. *Global Purchasing Power Parities and Real Expenditures: 2005 International Comparison Program*. Washington, DC: World Bank.

World Bank. 2014. *Purchasing Power Parities and the Real Size of World Economies: A Comprehensive Report of the 2011 International Comparison Program*. Washington, DC: World Bank.

Notes:

(1.) Though this bias is weaker than it used to be; see, for example, Foster, Haltiwanger, and Krizan (2006) with a micro-level perspective on productivity in retail trade; Adamopoulos and Restuccia (2014) on farm size and productivity; or Chandra, Finkelstein, Sacarny, and Syverson (2016) on productivity dispersion in hospitals.

(2.) The work of Hsieh and Klenow (2009) and Bartelsman, Haltiwanger, and Scarpetta (2013) are notable exceptions.

(3.) Linked employer-employee data, as used in, e.g., Utar (2014), are an important exception.

(4.) See also Ortega-Argilés (2012) for a survey on the transatlantic productivity (growth) gap.

(5.) To be precise, this refers to changes in the pace of total factor productivity growth; Stiroh (2002) had shown a similar result for labor productivity growth in ICT-intensive industries. See also Chapter 3 of this volume for additional analyses of US data.

(6.) See, e.g., Inklaar et al. (2008) or Inklaar and Wang (2011) specifically on measuring real output of banks.

(7.) The second and third application draw heavily on Inklaar (2015).

(8.) Though even when these conditions are not satisfied, aggregate TFP growth can be meaningful in tracking consumer welfare; see Basu, Pascali, Schiantarelli, and Servén (2014).

(9.) Data on the skill composition of the workforce can be typically be collected from household surveys, while a breakdown of industry investment by type of asset can be available either from detailed tabulations by statistical agencies or estimates by researchers based on additional surveys.

(10.) See O'Mahony and Timmer (2009) and Timmer, Inklaar, O'Mahony, and van Ark (2010) for a detailed description of the data, and see www.euklems.net for the data.

The Industry Sources of Productivity Growth and Convergence

(11.) And even within the ICT production sector, the share of ICT manufacturing and ICT services are comparable, though in the United States the semiconductor industry is much more important and concentrated in products that have generated most TFP growth since 1995.

(12.) In the March 2007 version of the EU KLEMS database, the finance and business services industry showed an annual average TFP growth of 0.9 percent between 1995 and 2004. These numbers are from the *SIC*-based data set; the data set based off the newer NAICS industry classification system showed growth of 0.5 % for the finance and business services industry. In the March 2008 release, growth for the 1995–2004 period had declined to –0.2%. The data in the March 2013 release, used here, show growth for the 1995–2004 period of –0.7%. These revisions are primarily due to differences in value-added growth in more recent vintages of the GDP-by-industry accounts of the US Bureau of Economic Analysis.

(13.) See, e.g., Restuccia, Yang, and Zhu (2008), Vollrath (2009), Herrendorf and Valentinyi (2012), Lagakos and Waugh (2013), and Gollin, Lagakos, and Waugh (2014) on industry productivity differences; on structural change, see, e.g., Duarte and Restuccia (2010), McMillan and Rodrik (2011), and Herrendorf, Rogerson, and Valentinyi (2014).

(14.) See, e.g., Bernard and Jones (1996), Inklaar and Timmer (2009), and van Biesebroeck (2009) on industry-level convergence across OECD countries. See, e.g., Restuccia, Yang, and Zhu (2008), Vollrath (2009), and Gollin, Lagakos, and Waugh (2014) on the role of agricultural productivity; and see Rodrik (2013) on manufacturing.

(15.) If $y_m > 0$, then net output m is an output and y_m denotes the production of this commodity; if $y_m < 0$, then net output m is an intermediate input and y_m denotes the negative of the amount of this input that is used by the production unit.

(16.) Assuming that $v_{kt} = V_{kt}$ so that the data are consistent with the constant returns to scale assumption required for implementing the Diewert-Morrison methodology.

(17.) Note that equations (22.12) and (22.13) imply that $P_{11} = 1$ and $Y_{11} = v_{11}$.

(18.) Note that our normalizations will imply that $Y_{11} = X_{11} = v_{11} = V_{11}$.

(19.) Index number methods for computing productivity go back to Jorgenson and Griliches (1967).

$$(20.) Y_{kt^*} \equiv v_{kt} / \left\{ P_{kt^*} \left[\prod_{j=1}^K \prod_{s=1}^T v_{js} \right]^{\frac{1}{KT}} \right\}.$$

(21.) “World” productivity here means the productivity of the aggregate of the productivity levels of the K countries in the sample for each time period t .

(22.) Capital compensation is determined as value added minus labor compensation. Aggregate compensation and employment data from PWT are used to extrapolate data

from the final year covered in the Socio-Economic Accounts to 2011; note that this extrapolation is only used to update cost shares, not for estimating industry productivity growth.

(23.) See World Bank (2008) for the description of the 2005 survey and results, and World Bank (2014) for the 2011 results.

(24.) See Inklaar and Timmer (2014) for more details on the mapping procedure and the adjustment for taxes and distribution margins.

(25.) Studies using these data are, e.g., Caselli (2005), Vollrath (2009), and Restuccia et al. (2008).

(26.) See, e.g., Inklaar et al. (2008) on diverging productivity growth patterns in market services across Europe and the United States after 1995.

(27.) See also, e.g., Inklaar et al. (2008) and McMorrow et al. (2010) for applications of this model to the setting of industry productivity growth in Europe.

(28.) In contrast to the “transatlantic growth gap” section, industry productivity growth here is (1) computed based on gross output rather than value added; and (2) relies on data from the WIOD’s Socio-Economic Accounts (SEA), rather than EU KLEMS, to increase country coverage. The main difference between these two sources is that the SEA capital input variable is not based on the capital services concept, whereby assets with different marginal costs are weighted differently, but rather are based on a capital stock concept.

(29.) The work by Ang et al. (2011) shows that the results of Vandebussche et al. (2006) are relevant not only for high-income but also for middle-income countries.

(30.) See also Cameron, Proudman, and Redding (2005).

(31.) See also Alfaro, Chanda, Kalemli-Ozcan, and Sayek (2010), Bloom, Sadun, and van Reenen (2012), and Cipollina, Giovannetti, Pietrovit, and Pozzolo (2012) with various perspectives on the role of FDI for productivity.

(32.) See also Griffith, Harrison, and Simpson (2010) for an industry-level analysis.

Robert Inklaar

Robert Inklaar, University of Groningen

